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Radio resource allocation based on adaptive and maximum reuse distance for LTE-V2X sidelink mode 3

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Abstract: LTE-V2X is one of the promising wireless technologies for Vehicle to Everything (V2X), which is expected to enhance the safety of road traffic. In this paper, we propose a radio resource allocation scheme for LTE-V2X Sidelink Mode 3. The reliability of packet transmission is seriously affected by changes in vehicle density. To cope with this issue, our new scheme reuses radio resources efficiently by calculating the range of protection from mutual interference based on the vehicle density. Compared with existing schemes, the proposed scheme successfully maintains a lower error rate of packet transmission regardless of the vehicle density.

Keywords: LTE-V2X, sidelink, radio resource allocation

Classification: Wireless Communication Technologies

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1 Introduction

In future mobility, all vehicles are expected to be connected and communicate in real-time to enable new services and applications. One of these services is cooperative recognition services. These services are aimed at improving traffic conditions and enabling cooperative autonomous driving, by periodically exchanging information on vehicle status, speed, and direction of travel. Cellular-V2X (C-V2X), which is based on mobile communication technologies such as LTE and 5G, is considered to be a promising communication system to achieve this.

For LTE-V2X, 3GPP has specified Sidelink Mode 3 and Mode 4. In Mode 3, the base station is responsible for scheduling the radio resources for the vehicle, while in Mode 4, the vehicles sense and select the resources autonomously. 3GPP provides the procedure for Mode 4, while the scheduling for Mode 3 is left to the operator. This paper focuses on the scheduling, i.e., radio resource allocations, for Mode 3.

So far, some Mode 3 radio resource allocation schemes for cooperative recognition services have been proposed. For instance, Fixed Reuse Distance (FRD) scheme [1] aims to reduce interference by blocking the reuse of radio resources currently used by vehicles within a certain distance, and Maximum Reuse Distance (MRD) scheme [2] aims to reuse radio resources used by the farthest vehicle. FRD, however, has the problem of over-blocking resources when the vehicle density is low. On the other hand, MRD cannot leave enough distance between vehicles that use the same resources when the vehicle density is high.

This paper proposes Adaptive and Maximum Reuse Distance (AMRD) scheme to solve the above two schemes. This scheme flexibly calculates the reuse distance of radio resources to protect them from mutual interference according to the vehicle density and further maximizes the space between transmitters using the same resources. Our simulation results show the effectiveness of AMRD by comparing it with other schemes.

2 Related works

In the cooperative recognition service, each vehicle periodically sends a beacon message with a certain generation period and size. The message is intended to be received by all neighbors within a given distance from each vehicle. In this paper, we call this distance the awareness range, r_{aw} . Sidelink Mode 3 assumes that the area is under the coverage of the network. The resource manager in the base station allocates resources to all vehicles at each allocation interval. Vehicles use the same RBs until they are reallocated. A schematic representation of radio resource allocation is shown in Fig. 1.

2.1 Fixed reuse distance scheme

FRD incorporates the concept of reuse distance, r_{reuse} [3], which is the minimum required distance that different transmitters can use the same resource without affecting the receivers in r_{aw} . According to [3], the reuse distance is calculated as follows:

$$r_{reuse} = r_{aw} + \frac{r_{aw}}{\left[\frac{1}{\gamma_{min}} - \frac{P_{nRB}}{P_{txRB}} \cdot \frac{L_0 \cdot r_{aw}^\beta}{G_r} \right]^{\frac{1}{\beta}}}, \quad (1)$$

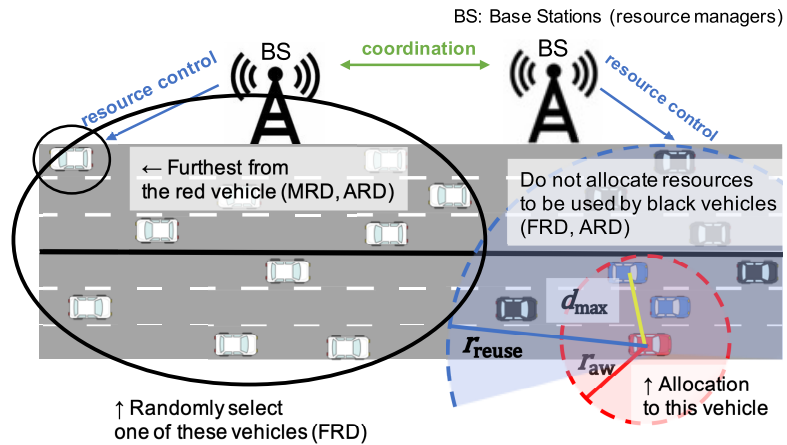


Fig. 1. Radio resource allocation for Sidelink Mode 3

where γ_{\min} is the minimum SINR necessary to receive the beacons correctly, P_{txRB} is the transmission power per resource block (RB), P_{nRB} is the noise power over an RB, L_0 is the path loss at 1 m, β is the loss exponent, and G_r is the antenna gain at the receiver. This equation relies on the assumption that the nearest interferer affects dominantly. This equation guarantees that a vehicle at r_{aw} away from the vehicle to be allocated can successfully receive beacons even if another vehicle at r_{reuse} away utilizes the same resource.

This scheme allocates radio resources to each vehicle as follows: A target vehicle is allocated radio resources not used, if any, within its r_{reuse} . For example, in Fig. 1, radio resources that the black vehicles do not use are available to the red vehicle. The resource manager randomly selects radio resources from the available ones if any. Otherwise, the transmission is blocked.

In each allocation interval, resources are reallocated first to the vehicles whose transmissions were blocked, and then to all vehicles that were previously allocated in the allocation interval.

The problem with FRD is that r_{reuse} is a fixed value. In the field of vehicle-to-vehicle (V2V) communication, the situation of the devices is volatile, and the area where interference may occur changes accordingly. For example, the range of protection from interference is very different when the maximum communication distance is r_{aw} and when a few meters is sufficient. Using an overlarge r_{reuse} reduces the number of candidate resources for allocations. As a result, transmission is over-blocked even when the possibility of interference is low.

2.2 Maximum reuse distance scheme

MRD does not use the reuse distance so that no allocations are blocked. Alternatively, the scheme selects and allocates the radio resources that are unused or used by the furthest vehicle.

The procedure of the allocation is as follows: Radio resources to be allocated are randomly chosen from unused ones if any. Otherwise, radio resources used by the furthest vehicle are allocated.

The problem with MRD is that it does not take into account the usage of radio resources by neighbor vehicles. For example, in Fig. 1, even if the resource used by

the white car furthest from the red car is allocated, if a black vehicle is also using the same resource, then the red vehicle will be more susceptible to interference.

3 Adaptive and maximum reuse distance scheme

3.1 Basic idea

AMRD was devised to overcome the problems of FRD and MRD. AMRD is based on MRD and incorporates an adaptive reuse distance, r_{reuse}^* , inspired by the concept of the reuse distance in FRD. This is not fixed like the reuse distance but is calculated dynamically by checking the positional relationship between the vehicle to be assigned and the surrounding vehicles. By replacing r_{aw} with the maximum distance, d_{max} , of the furthest vehicle within r_{aw} in Eq. (1), r_{reuse}^* is calculated as follows:

$$r_{\text{reuse}}^* = d_{\text{max}} + \frac{d_{\text{max}}}{\left[\frac{1}{\gamma_{\min}} - \frac{P_{\text{nRB}}}{P_{\text{txRB}}} \cdot \frac{L_0 \cdot d_{\text{max}}^\beta}{G_r} \right]^{\frac{1}{\beta}}}, \quad (2)$$

where $d_{\text{max}} \leq r_{\text{aw}}$ and d_{max} is as shown in Fig. 1.

3.2 Operation of AMRD

This allocates radio resources as follows: First, the resource manager computes r_{reuse}^* of a target vehicle. Then, the resources used by the vehicles in r_{reuse}^* , i.e. the black vehicles in Fig. 1, are identified and marked. The resources in this list are not reused to prevent them from interfering with each other. The radio resource to be assigned is randomly selected from the unused ones, if any. Otherwise, the resource manager allocates the radio resource that is not on the list and is in use by the furthest vehicle. If no resource is available, the transmission is blocked. In each allocation interval, resources are reallocated first to the vehicles whose transmissions were blocked, and then to all vehicles that were previously allocated in the allocation interval.

4 Performance evaluation

4.1 Simulation settings

In this section, we verify the effectiveness of AMRD by evaluating it against two existing schemes in the aspect of the reliability of packet transmission. The simulator used is LTE-V2Vsim [4] written in MATLAB. We assume a scenario that simulates a highway. In the scenario, we examine the impact of changes in vehicle density on the packet reception rate. In addition to FRD, MRD, and AMRD, we also evaluated two other schemes: one is that combines FRD and MRD (called FMRD), and the other is that replaces r_{reuse} in FRD with r_{reuse}^* (called ARD).

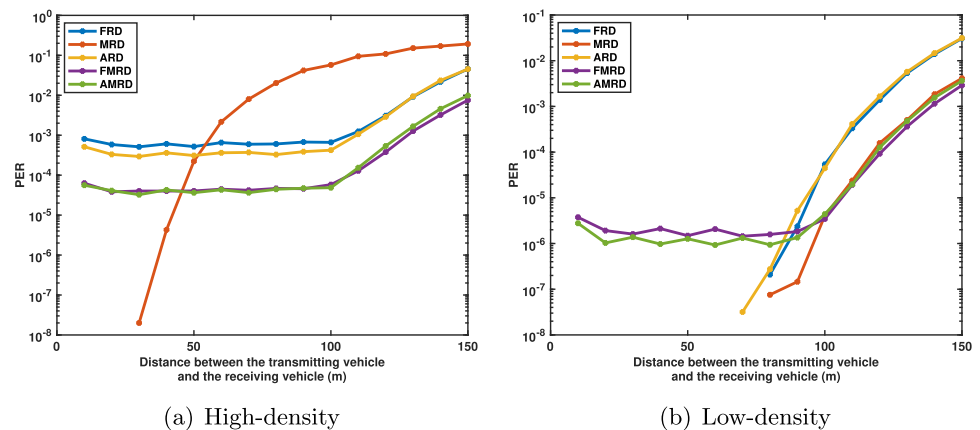
The evaluation metric is the Packet Error Rate (PER), which is the ratio of the total number of packets that failed to transmit to the total number of transmission attempts. The packets that failed to transmitted include packets that were blocked transmission. The success or failure of transmission and reception is judged by comparing the measured SINR with an initial set threshold value γ_{\min} . The simulation settings are summarized in Table I.

Table I. Simulation and scenario settings

Parameter	Value
Simulation time	500 s
Allocation interval	0.1 s
Beacon size	300 bytes
Central frequency	5.9 GHz
Channel bandwidth	10 MHz
Equivalent Radiated Power	23 dBm
Tx/Rx antenna gain	3 dB
Path loss model	WINNER + (B1)
Antenna height	1.5 m
Shadowing decorrelation distance	25 m
Shadowing standard deviation	3 dB (LOS)
Duplexing	HD
Noise power over a RB	−110 dBm
Modulation and coding scheme (MCS)	3
Awareness range (r_{aw})	150 m
Road length	2 km
Number of lanes	4
Lane width	3 m
Vehicle speed	80 km/h
Average number of vehicles	200
Vehicle density (High-density)	143 vehicles/km
Vehicle density (Low-density)	48 vehicles/km

4.2 Results

Figure 2 shows the PER for each scenario. These graphs are one-logarithmic. The vertical axis in the logarithmic scale denotes the PER, and the horizontal axis represents the distance in meter between the transmitting and receiving vehicles. From Fig. 2(a), we consider that setting the reuse distance like FRD and selecting resources like MRD is one solution to maintain reliability when the vehicle density is high. Because there is no noticeable difference between FMRD and AMRD, we can recognize that there is little benefit from varying the reuse distance in high-density scenario. On the other hand, Fig. 2(b) shows that AMRD has somewhat

**Fig. 2.** Simulation results

a smaller PER at the communication distance up to 100 m than FMRD, thanks to varying the reuse distance, in the low-density scenario. Figure 2(a) displays that ARD outperforms FRD slightly in short-distance communication in the high density scenario. Still as the communication distance is longer, the PER of ARD is approaching that of FRD. The performance at low density is also the same as FRD as shown in Fig. 2(b).

From the above results, we conclude that AMRD can guarantee transmission reliability regardless of the vehicle density. In short-range communication, however, the PER of AMRD is sometimes higher than in other schemes. That is because the allocation constraint of AMRD is still too strict than other schemes, and some transmissions are blocked even when the number of transmission errors is small.

5 Conclusion

In this paper, we proposed a new radio resource allocation scheme that takes advantage of the characteristics of existing allocation schemes in V2V. The simulation results showed that the proposed scheme could keep the PER low regardless of the vehicle density. It was, however, revealed that the success rate of close-range communication might be lower than that of existing schemes due to the presence of some transmission blocks, even if the number of transmission errors is small.

In the future, we would like to verify the effectiveness of AMRD in scenarios based on actual road conditions.

Acknowledgments

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